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AIRMOD--A GENERAL PROGRAM FOR THE RAPID ASSESSMENT OF AIRBORNE --ETC(U)
AUG 78 R D WEBSTER, R L WELSH, P K TERKONDA

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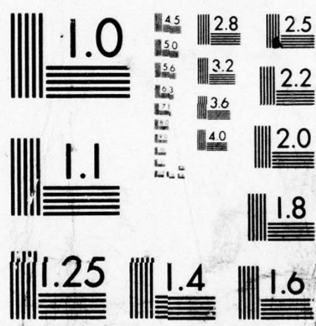


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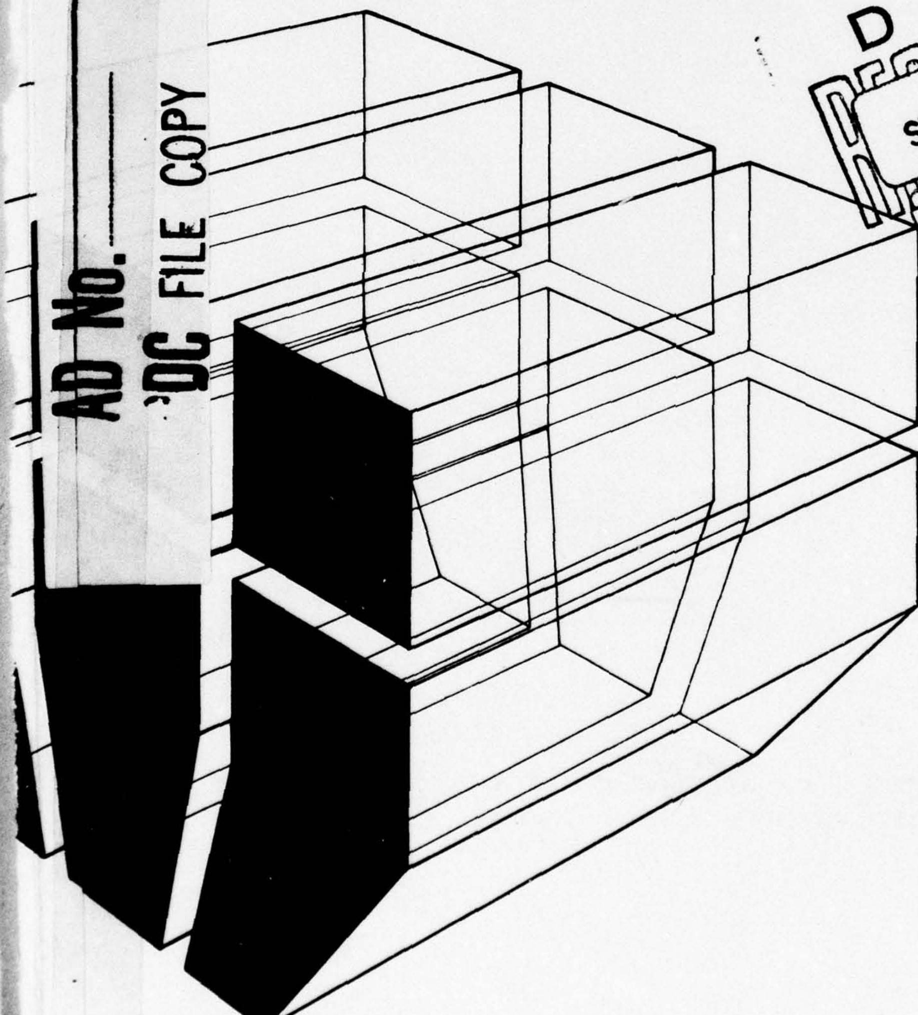
INTERIM REPORT N-52
August 1978
Development of Environmental Technical Information System

# AIRMOD—A GENERAL PROGRAM FOR THE RAPID ASSESSMENT OF AIRBORNE POLLUTANTS





by
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This report describes the initial design of a general program for the rapid assessment of airborne pollutants (AIRMOD). The system includes procedures for (1) long-term and short-term evaluations, (2) the determination of point and line source emitters, (3) limited mixing conditions, and (4) corrections for major topographic features. AIRMOD output is presented as a table of pollutant concentration estimates for all possible weather conditions. The basic model is Gaussian plume dispersion of conservative pollutants. Its primary application is for → CONT'

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sulfur oxides, carbon monoxide, and particulates less than 10 microns in diameter. Models for other types of pollutants are still under consideration.

## FOREWORD

This project was performed for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities," Task 01, "Environmental Quality Management for Military Facilities," Work Unit 006, "Analytical Model System for Prediction of Environmental Impacts." Dr. L. Schindler, DAEN-MCE-D, was the OCE Technical Monitor.

This research was made possible through the efforts of the scientists and engineers of the U.S. Army Construction Engineering Research Laboratory (CERL) and the scientists of the University of Illinois and University of Missouri.

Administrative support and counsel were provided by Dr. R. K. Jain, Chief of the CERL Environmental Division.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

AIRMOD--A GENERAL PROGRAM FOR THE RAPID ASSESSMENT OF AIRBORNE POLLUTANTS

# 1 INTRODUCTION

## Background

The National Environmental Policy Act (NEPA) established the requirement for all Federal agencies to assess the environmental impact of their programs and activities. Department of the Army (DA) guidance[2,3] has firmly established the importance of cognizance and concern for the air quality on and adjacent to DA installations. Monitoring and abatement methodologies require detailed study and the current state of the art for conducting both activities, although often expensive, is adequate. The assessment methodologies are, however, inadequate. Assessment tools which can define within resource limits the magnitude of anticipated air pollution problems are required by AR 200-1. The user must be capable of attaining "first cut" estimates of pollution levels in a timely and efficient manner, so that the Army can comply with environmental assessment requirements. Data input requirements must be kept at a minimum and the system must provide all data necessary to assure an adequate assessment at minimum cost.

The Construction Engineering Research Laboratory (CERL), through the development of the Environmental Technical Information System (ETIS), has developed the concept of general models for the assessment of environmental impact as part of the Regional Impact Assessment System. These general models will be designed to aid the environmental assessment process and will of necessity be less sophisticated than many existing techniques. The greater sophistication, cost, and user requirements inherent to many existing models are only reasonable if the resultant output is available in a timely manner and is sufficiently more accurate or dependable to the extent that it would impact decisions being made. The general models can aid in the screening and analysis of original alternatives. The more sophisticated techniques are better suited to the analysis of specific cases and problem areas.

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1 National Environmental Policy Act of 1969, 83 Stat 852, 42 USC 4321 et seq. (January 1970).

2 *Environmental Protection and Enhancement*, Army Regulation (AR) 200-1 (Department of the Army, February 1974).

3 *Handbook for Environmental Impact Analysis*, DA Pamphlet 200-1 (Department of the Army, April 1975).

## Objective

The overall objective of this study is to develop easily accessible, inexpensive methodologies to aid the Army in preparing environmental impact assessments of air quality.

This report documents the design and development of a prototype computer-aided method for assessing the dispersion of air pollutants. It outlines (1) the general design of the system, (2) the theoretical basis for estimating pollutant concentrations via the system, and (3) a preliminary user manual for computer implementation of the prototype system.

## Approach

Existing predictive techniques[4] were reviewed and evaluated for suitability to environmental assessment. Numerical algorithms were selected to meet user requirements and a plan for implementing them into the air quality impact model concept was developed. User input requirements and the format of the model output were investigated and documented.

## Mode of Technology Transfer

The AIRMOD computer program will be disseminated in accordance with procedures set forth in AR 18-1, *Management Information Systems Policies, Objectives, Procedures, and Responsibilities* (Department of the Army, March 1976).

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[4] David F. Menicucci, *Air Quality Assessment Model (AQUAM) Data Reduction and Operations Guide* (Air Force Weapons Laboratory, Air Force System Command, Kirtland AFB, December 1975); UNIMAP Models (Environmental Protection Agency, 1972 to 1977).

## 2 THE FUNCTION OF GENERAL AIR POLLUTION ASSESSMENT MODELS AND THEIR CONSTRAINTS

### The Function of General Models

An air pollution impact assessment model should be capable of determining one or more of the following: (1) the spatial distribution of pollutant concentration, (2) the pollutant levels at a point, and (3) the maximum pollutant concentration and its point of occurrence.

Spatial concentration distribution may be represented by isopleths, which are points of equal concentration. The resultant map indicates the zones in which specific levels of pollutant concentration are anticipated. This sort of analysis requires extensive computer time and usually requires specialized hardware (e.g., a plotter or graphics display). When evaluating maximum concentration levels, the user is interested only in the location and magnitude of the maximum impact. The need to determine the concentration at a point is the result of a localized concern for the effects of a source on a geographic location which, for one reason or another, happens to be a particularly sensitive area (e.g., residential dwellings or habitat for a sensitive species). The assessment of impact is based upon the concentrations of pollutants estimated to occur at a specific point.

### Constraints on Model Development

Three primary user requirements considered in the design of the assessment model were: (1) responsiveness, (2) geographic coverage, and (3) cost considerations.

The model must respond to inquiries rapidly and without sophisticated data acquisition, input, or analysis requirements. A model requiring time-consuming acquisition of project-specific data will limit its use by precluding the rapid analysis of many different project alternatives.

The model should not be regionally specific, or, if so, it should incorporate a data base sufficient for use in the limited assessment of alternatives across the entire United States. Regionally specific models, while adequate for their particular area, cannot provide the DA user with the necessary flexibility.

The model must be selected to insure efficient utilization of the DA user's designated funds. A model which incurs expense beyond designated funding must provide an increased volume and quality of useful information to justify its expense. Because complexity is often

correlated with higher expense and with the requirement for greater expertise, the typical DA user is limited to the use of general models, and to sacrificing some accuracy in the interest of planning and budget efficiency. This constraint precludes the use of many of the current, complex air pollution impact assessment models.

## Types of Air Pollution Impact Assessment Models

Air pollution impact assessment models in general can be classified by source type and pollutant type. These models can be employed for the assessment of either short-term or long-term impacts. Traditional short-term measures are steady-state 10-minute, 1-hour, or 24-hour concentrations. Long-term concentrations are monthly, seasonal, or annual averages taking into account historical meteorological data for the time period under study.

### *Source Type*

Three types of general sources are recognized: (1) the point source, (2) the line source, and (3) the area source.

Point source, being the simplest, is the most common. In this case, the pollutants are emitted from an identifiable stationary source such as an industrial facility gas stack. The emissions are discharged through the stack and are diffused into the atmosphere. In the absence of topographic effects, the resultant pollutant pattern theoretically forms a series of concentric circles about the stack centerline. Although this very rarely occurs in nature, the idealized concept is useful for visualization purposes.

Line source can be defined as an infinite series of point sources aligned along one directional axis, such as a highway. Although in reality line sources, like highways, are often curvilinear, this concept is workable if the curved line is viewed as a series of small, straight-line segments.

An area source is defined as a large number of point sources concentrated within a specific geographic area, such as the city of Chicago.

### *Pollutant Type*

Pollutants can be classified according to either their chemical properties or their physical characteristics and are considered either conservative or nonconservative based upon whether they are removed by

atmospheric processes. Nonconservative pollutants include nitrogen oxides, hydrocarbons, oxidants, and particulates. The modeling of non-conservative pollutant dispersion is a complex phenomenon that is beyond the scope of this report.

Pollutants can be treated as either gases or particulates depending upon their particle size. Particles less than 20 microns in diameter behave like gases due to their long residence times in the atmosphere, while those greater than 20 microns in diameter are treated as particulates because of their appreciable settling velocity. In the 10 to 20 micron range it is necessary to make a case-by-case determination, the main considerations being the relative effects of buoyancy and gravity.

## Special Cases

In addition to the above model types, consideration must also be given to certain special conditions which can modify concentration estimates. These may be of a physical or phenomenological nature.

Limited mixing conditions: conditions occur when the natural dispersion of pollutants is restricted, trapping them below a stagnant inversion layer. This limited mixing condition could develop into a situation known as fumigation in which the plume actually touches the ground.

Topography: while gentle slopes and small undulations will have minimal effect on the dispersion pattern of pollutants into the atmosphere, larger topographic variations can significantly affect ground level pollutant concentrations.

Sea breeze influence: the effects of a large body of water adjacent to the study area upon wind patterns can be significant as cool and warm air masses interact.

## 3 THE AIR POLLUTION DISPERSION MODEL (AIRMOD) -- THEORY

The preceding chapter outlined the function of general air pollutant impact assessment models and their constraints. The following chapters will highlight the approach taken by CERL in the development of the Air Pollutant Dispersion Model (AIRMOD). AIRMOD will fulfill the DA users' need for a widely applicable assessment tool. For complex situations, more sophisticated models may be required to estimate the air quality impact.

### Basic Equation

As shown in Figure 1, the x-axis is defined to extend horizontally away from the source in the direction of the wind; the y-axis is another horizontal line running perpendicular to the x-axis; and the z-axis extends vertically from the base of the emitting stack.

Ideal dispersion of a pollutant in three dimensions then may be represented by Gaussian distributions:

$$c(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u} e^{\frac{-y^2}{2\sigma_y^2}} \left\{ e^{\frac{-(z-H_e)^2}{2\sigma_z^2}} + e^{\frac{-(z+H_e)^2}{2\sigma_z^2}} \right\} \qquad \text{[Eq 1]}$$

where:
- $c$ = concentration at x, y, z ($y/m^3$)
- $H_e$ = effective stack height (m)
- $Q$ = emission rate (g/sec)
- $\sigma_y$ = lateral dispersion coefficient (m)
- $\sigma_z$ = vertical dispersion coefficient (m)
- $u$ = wind speed at stack height (m/sec).

For centerline concentrations ($y = 0$) at ground level ($z = 0$), this reduces to:

$$c(x,0,0) = \frac{Q}{\pi\sigma_y\sigma_z u} e^{\frac{-H_e^2}{2\sigma_z^2}} \qquad \text{[Eq 2]}$$

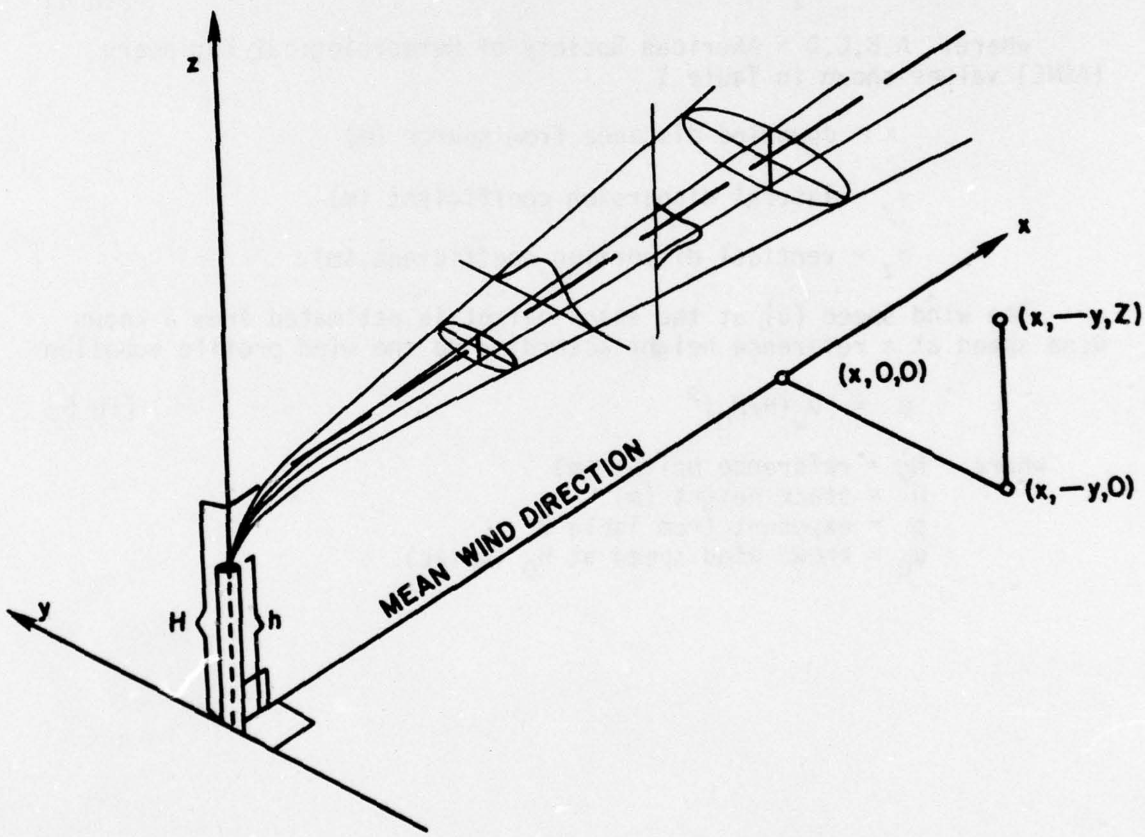


Figure 1. Coordinate system showing Gaussian distributions in the horizontal and vertical directions.

Inherent assumptions in this ideal case are

1. A steady state condition has been reached
2. The pollutant is conservative.

In order to evaluate the basic equation, it is first necessary to determine the values of the dispersion coefficients ($\sigma_y$ and $\sigma_z$), the wind speed at stack height (u), and the "effective" stack height (h).

The dispersion coefficients (also known as diffusion factors) are determined by the equations

$$\sigma_y = Ax^B \quad \text{[Eq 3]}$$

$$\sigma_z = Cx^D \quad \text{[Eq 4]}$$

where: A,B,C,D = American Society of Meteorological Engineers (ASME) values shown in Table 1

x = downwind distance from source (m)

$\sigma_y$ = lateral dispersion coefficient (m)

$\sigma_z$ = vertical dispersion coefficient (m).

The wind speed (u) at the stack height is estimated from a known wind speed at a reference height according to the wind profile equation:

$$u = u_0(H/H_0)^p \quad \text{[Eq 5]}$$

where: $H_0$ = reference height (m)
$H$ = stack height (m)
$p$ = exponent from Table 2
$u_0$ = known wind speed at $H_0$ (m/sec).

Table 1
ASME Dispersion Parameter*

| Stability Class | All units in meters A | B | C | D |
|---|---|---|---|---|
| 1 | 0.40 | 0.91 | 0.40 | 0.91 |
| 2 | 0.36 | 0.86 | 0.33 | 0.86 |
| 3 | 0.32 | 0.78 | 0.22 | 0.78 |
| 4 | 0.31 | 0.71 | 0.06 | 0.71 |
| 5 | 0.40 | 0.91 | 0.40 | 0.91 |
| 6 | 0.36 | 0.86 | 0.33 | 0.86 |
| 7 | 0.32 | 0.78 | 0.22 | 0.78 |

Table 2
Wind Profile Parameters+

| Exponent | Stability Class 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| p | 0.10 | 0.12 | 0.20 | 0.30 | 0.10 | 0.12 | 0.20 |

* *Recommended Guide for the Dispersion of Airborne Effluents*, second edition (American Society of Meteorological Engineers [ASME], 1973).

+ Demarrais, G. A., "Wind Speed Profiles at Brookhaven National Laboratory," *Journal of Applied Meteorology*, Vol 16 (1969), pp 181-189.

The effective stack height is the actual stack height plus the vertical distance the pollutants rise due to buoyancy and momentum before beginning to disperse.

*Momentum Rise*

Momentum rise is usually insignificant unless the exit velocity is greater than 10 m/sec. The empirical equation reported by Briggs[5] was

$$\Delta H = 1.89D \left\{ \frac{R}{1+\frac{3}{R}} \right\}^{\frac{2}{3}} \left(\frac{X}{D}\right)^{\frac{1}{3}} \quad \text{[Eq 6]}$$

where: D = stack diameter (m)
R = ratio of stack gas exit velocity to wind speed (m/sec)
H = plume rise (m)
x = downwind distance from source (m).

Buoyant rise is also determined by empirical equations published by Briggs. First, a buoyancy flux (F) is calculated according to

$$F = 2.45vD^2 \frac{T_s - T_a}{T_a} \quad \text{[Eq 7]}$$

where: D = stack diameter (m)
$T_a$ = ambient air temperature ($^oK$)
$T_s$ = stack gas exit temperature ($^oK$)
v = stack gas exit velocity (m/sec).

The equation for calculating rise will use this buoyancy flux term, but the technique will differ depending on the stability class of the atmosphere (see Appendix for a discussion of stability classes as they are used in AIRMOD).

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[5] Briggs, Gary A., *Some Recent Analysis of Plume Rise Observations* (Second Clean Air Congress).

For unstable or neutral atmospheres (stability classes 1 through 3), a critical distance ($\hat{x}$) is calculated such that

$$\hat{x} = 14F^{\frac{5}{8}} \quad \text{if } F \leq 55 \frac{m^4}{sec^3} \qquad \text{[Eq 8]}$$

$$\hat{x} = 34.49F^{\frac{2}{5}} \quad \text{if } F > 55 \frac{m^4}{sec^3} \qquad \text{[Eq 9]}$$

The plume rise (H) is then determined by

$$\Delta H = \frac{1.6F^{\frac{1}{3}}x^{\frac{2}{3}}}{u} \qquad \text{[Eq 10]}$$

where: F = buoyancy flux ($m^4/sec^3$)
u = wind speed at stack height (m/sec)
x = downwind distance or 3.5 $\hat{x}$, whichever is smaller (m).

For stable atmospheres (stability class 4), the temperature gradient of the atmosphere becomes important. Accordingly, a stability factor (S) is defined by

$$S = \frac{9.8}{T_a}\left(\frac{dT}{dz} + \Gamma\right) \qquad \text{[Eq 11]}$$

where: $T_a$ = ambient air temperature ($^oK$)

$\frac{dT}{dz}$ = atmospheric temperature gradient ($^oK/m$)

$\Gamma$ = adiabatic lapse rate (0.0098 $^oK/m$).

For distance (x) less than $\frac{\pi u}{S^{1/2}}$, rise is calculated as in Eq 10.

However, for larger distances, two estimates must be made

$$\Delta H_1 = 2.9\left(\frac{F}{uS}\right)^{\frac{1}{3}} \qquad \text{[Eq 12]}$$

$$\Delta H_2 = \frac{5F^{\frac{1}{4}}}{S^{\frac{3}{8}}} \qquad \text{[Eq 13]}$$

The smaller of the two ($\Delta H_1$ and $\Delta H_2$) is selected for the plume rise.

Now the total effective height ($H_e$) may be computed as

$$H_e = H + \Delta H_{momentum} + \Delta H_{buoyant} \qquad \text{[Eq 14]}$$

<u>Inversion Conditions</u>

When inversion conditions exist, the resulting concentration distribution is classified into three zones: (1) an unaffected zone near the source, (2) an "affected" zone, and (3) a vertically uniform zone far from the source. The distance $x_1$ is the value of x when

$$\sigma_z = 0.47L \qquad \text{[Eq 15]}$$

where: L = height of the base of inversion layer

$x_1$ will be used to define the limits of each of the three zones.

The unaffected zone extends from the source to a distance $x_1$ from the source. If the inversion layer is higher than the effective stack height, the pollutant distribution in this zone is unaffected. Concentrations are calculated using the basic equation exactly as if no inversion existed. In actuality, though, the effective stack height cannot be greater than the height of the inversion layer since the pollutants would be "trapped" or confined to the lower layer. So, if the models for plume rise indicate a greater value, the height of the inversion layer (L) is used for effective stack height ($H_e$) in the basic equation.

From $x_1$ to $2x_1$ is an "affected" zone. No model exists for the pollutant distribution in this area. However, concentrations are estimated by assuming an exponential relationship with distance and extrapolating from the pollutant concentration values at $x_1$ and $2x_1$.

In the vertically uniform zone (beyond $2x_1$) the inversion layer has limited the vertical mixing to such an extent that the pollutant distribution has been smoothed out vertically and is uniform from the ground

to the inversion layer. The only dispersion that occurs is lateral. Accordingly, the concentration (c) in this zone is given by

$$c(x,0,0) = \frac{Q}{\sqrt{2\pi} L u \sigma_y} \qquad \text{[Eq 16]}$$

where: $L$ = height of the inversion layer (m)
$Q$ = emission rate (g/sec)
$c$ = concentration ($g/m^3$)
$u$ = wind speed at stack height (m/sec)
$\sigma_y$ = lateral dispersion coefficient (m).

## Topographic Effects

Local topography can profoundly affect expected pollutant concentration levels (via streamlining, turbulence, etc.). Unfortunately, the treatment of this type of phenomenon is far beyond the scope of a general, widely applicable model. However, a corrective term may be incorporated to adjust for the difference in elevation between the point of pollutant emission and the points for which pollutant levels are to be determined. Differences in elevation cause an apparent increase or decrease in the effective stack height. Thus, the new effective stack height ($H_n$) is

$$H_n = H_e + (E_s - E_r) \qquad \text{[Eq 17]}$$

where: $H_e$ = effective stack height (m)
$H_n$ = new effective stack height (m)
$E_s$ = ground elevation at the pollutant source (m)
$E_r$ = ground elevation at the pollutant receptor (m).

## Long-Term Averages

The basic equation, as previously noted, is applicable for short-term estimates where the meteorological conditions are assumed to be constant. Over long periods this is obviously not true. A long-term estimate may be obtained, however, if site-specific meteorological data giving the observed frequency distributions for stability class and wind speed class are available. The "wind rose" data of the National Climatic Center provide this information for the 16 cardinal wind directions. Using these data, a long-term concentration may be calculated by taking an average, weighted by frequency of occurrence, of all

stability classes and wind speed classes. Mathematically this is

$$c(x,\theta) = \sum_{s=1}^{s=4} \sum_{w=1}^{w=4} \frac{2Qf(\theta,s,w)}{(2\pi)^{\frac{1}{2}}(\sigma_z)_s u_w \frac{2\pi x}{16}} e^{\frac{-h^2_{s,w}}{2(\sigma_z^2)_s}} \qquad \text{[Eq 18]}$$

where: $Q$ = emission rate (g/sec)
$f(\theta, s, w)$ = probability in stability class s with wind class w in direction $\theta$.
$h_{s,w}$ = effective stack height for stability class s and wind class w (m)
$(\sigma_z)_s$ = vertical dispersion coefficient for stability class s (m)
$u_w$ = mean wind speed for wind class w (m/sec).

## Line Source

The basic equation for a point source is extended to a line source by considering the line to be an infinite number of points, calculating the contribution from each point, and adding. This amounts to integrating the basic equation along the line direction. For an infinite line, the result of this integration is

$$c(x,0,0) = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \frac{Q_1}{\sigma_z^* u \cdot \sin(\phi)} \qquad \text{[Eq 19]}$$

where: $Q_1$ = source strength per unit length (g/sec-m)
$u$ = wind speed (m/sec)
$\phi$ = angle of wind with line source
$\sigma_z^*$ = vertical dispersion coefficient (m)

This is the basic equation for a line source. Topographic effects and long term calculations are analogous to those for a point source.

The source strength for a line source corresponds to the emission rate for a point source except that it depends, obviously, on the length of the line. In the basic line source equation, the source strength

refers to the emission rate per unit length. When the line is a highway, the source strength is

$$Q_l = N_v Q_v \qquad \text{[Eq 20]}$$

where: $N_v$ = number of vehicles per sec ($sec^{-1}$)
$Q_v$ = pollutant mass per vehicle per meter (g/sec-m).

The calculation of the dispersion coefficient $\sigma_x$ needs to be modified because: (1) the x-distance is not measured in the wind direction but at an angle, (2) the initial release of pollutant is actually from a moving point resulting in a pollutant cloud with a finite size. The equation is

$$\sigma_z = A(x^* + I)^B \qquad \text{[Eq 21]}$$

where: A = coefficient from Table 3
B = coefficient from Table 3
I = value from Table 3
$x^*$ = distance divided by cos $\emptyset_o$ (m).

Table 3
ASME Dispersion Parameter*

| Stability Class | All units in meters | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | I |
| 1 | 0.40 | 0.91 | 0.40 | 0.91 | 4.0 |
| 2 | 0.36 | 0.86 | 0.33 | 0.86 | 6.0 |
| 3 | 0.32 | 0.78 | 0.22 | 0.78 | 12.0 |
| 4 | 0.31 | 0.71 | 0.06 | 0.71 | 93.0 |
| 5 | 0.40 | 0.91 | 0.40 | 0.91 | 4.0 |
| 6 | 0.36 | 0.86 | 0.33 | 0.86 | 6.0 |
| 7 | 0.32 | 0.78 | 0.22 | 0.78 | 12.0 |

* *Recommended Guide for the Dispersion of Airborne Effluents*, second edition (American Society of Mechanical Engineers [ASME], 1973).

## 4 THE AIR POLLUTION DISPERSION MODEL (AIRMOD) -- USAGE

To gain access to AIRMOD, the user must request a number, name, and password from CERL at 217/352-6511, extension 385 (commercial) or 958-7385 (FTS). These codes will give the user direct access to the Environmental Technical Information System (ETIS) of which AIRMOD is an element.

ETIS will begin automatically when the user has successfully established communication with CERL's computer. The first response is:

Welcome to CERL's Environmental Technical Information System

For a complete list of ETIS programs, type a carriage return. For immediate access to AIRMOD, type 5. Successful access to AIRMOD is indicated by:

WELCOME TO AIRMOD

### Selecting the Model Type

AIRMOD will then request a model type. Model options available to the user are (1) point, (2) line, (3) short, (4) long, (5) limit, (6) detailed, and (7) topographic.

The selected options should all be typed on one line, followed by a carriage return. Any other words not in the option list may be included: "point short topographic" could alternatively be typed as "short-term point-source model with topographic data." To identify a valid model the user must include one of the options "point" or "line," and one of the options "short" or "long." "Point" and "line" as well as "short" and "long," are mutually exclusive; i.e., if "point" is specified, do not select "line" also.

The "point" option specifies that a point-source model is to be used. Data which AIRMOD will request is shown in Table 4.

The "line" option specifies that a line-source model is to be used. In the usual case, the "line" is a highway, so it is assumed that there is no plume rise since pollutants from vehicles are emitted at temperatures near the ambient temperature and with low vertical components of velocity. The data which AIRMOD will request for this model is shown in Table 5.

"Short" is the option for short-term calculations. No additional data is needed other than that required for either the "point" or "line" option. Short-term calculations depend on atmospheric stability class

Table 4
Data Requirements for Point-Source Calculation

| Data | Units |
|---|---|
| Emission rate | gr/sec |
| Stack height | m |
| Stack diameter | m |
| Stack gas exit velocity | m/sec |
| Stack gas exit temperature | degrees $^oK$ |
| Ambient temperature | degrees $^oK$ |
| Maximum positive lapse rate | oK/m |

Table 5
Data Requirements for Line-Source Calculation

| Data | Units |
|---|---|
| Number of vehicles per hour | cars |
| Pollutant vehicle/km | (gr/car)-km |
| Angle of wind with line source | degrees |

and wind speed, so the output from this option is a table showing concentration estimates for every stability class and wind class.

"Long" is the option to indicate when long-term concentrations are required. When the "long" option is selected, AIRMOD types:

Name of meteorological input file:

In response, the user types either the name of an existing data file, or a name to be given to the data file about to be created. If the name of an existing file is typed, AIRMOD will read the meteorological data from that file. Otherwise, AIRMOD will create a file with the user-assigned name and the user will be requested to type meteorological data. Each piece of data is specifically requested by AIRMOD.

Long-term concentrations depend on the average wind speed and average stability class. When this option is selected, the probability of occurrence of each stability class and wind class must be input. Input can be provided by (1) using the Unix "ed" command[6] to create a file of data, or (2) inputting data interactively as AIRMOD requests it.

If "ed" is used to create a file of meteorological data, it should contain the following information.

1. For each stability class there should be 16 lines of data. Each line corresponds to a particular wind direction. Line 1 is N, line 2 is NNE, line 3 is NE, and so on around the compass in clockwise order.

2. On each line there must be six numbers. These correspond to frequencies for a particular wind class 1 through 6.

3. The whole file then should contain four groups of data. Each group is 16 lines long with six numbers per line. These must be kept in order, i.e., stability class 1 is first, direction 0 (north) comes first within a stability class, and wind class 1 is the first entry on a line.

If "ed" has not been used to prepare a meteorological data file ahead of time, AIRMOD will prompt for each data value as needed and the meteorological file is created, and will store it under the user-assigned name. These data may then be used during any future AIRMOD sessions by simply typing the user-assigned name in response to the AIRMOD query "Name of meteorological input file."

---

[6] *Documents for Use with the Unix Time Sharing System* (Western Electric Company, 1975).

*"Limit" and "Detailed" Options*

The selection of the "limit" option will include limited mixing conditions in the model calculations. Seven stability classes will be used instead of four. Classes 5, 6, and 7 will refer to limited mixing classes (see Appendix). This option has no effect on the long-term calculations, since limited mixing conditions are not considered when figuring long-term averages.

Normally, calculations are carried out for one specified point. However, if several points are desired, the "detailed" option is selected. To use this option, an input file containing the distances for points of calculation must be supplied. AIRMOD will request:

Name of distances input file:

As for the "long" option, the user then types either (1) the name of an existing file containing distance data or (2) a name to be given to the file about to be created. AIRMOD then either reads data from the named file or interactively requests the necessary data.

If "ed" is used to create the distances file, the format should be as follows.

1. First line: <direction> <distance> <optional topo data>
2. Second line: <direction> <distance> <optional topo data>
3. Third line: <...etc...>

This file should contain one line for each distance for which pollutant concentrations are to be calculated. These should be in order according to direction and distance from smallest to largest. Wind directions are specified as a number 0 to 15 according to:

| | | | |
|---|---|---|---|
| 0 - N | 4 - E | 8 - S | 12 - W |
| 1 - NNE | 5 - ESE | 9 - SSW | 13 - WNW |
| 2 - NE | 6 - SE | 10 - SW | 14 - NW |
| 3 - ENE | 7 - SSE | 11 -WSW | 15 - NNW |

For example, a sample data file might contain:

```
0    500
0   1000
8    500
8   1000
```

This file will calculate concentrations at distances of 500 and 1000 m to the north (0) and to the south (8) of the source. It should be noted, however, that short-term calculations for these two directions

will be the same unless topographic data are supplied because frequency data and topography data provide the only directional dependence.

If "ed" has not been used to prepare a distance file ahead of time, AIRMOD will request each input individually and write the file in the correct format. It may then be referred to during future AIRMOD sessions by typing the user-assigned name in response to the AIRMOD query "Name of distances input file."

*Topographic*

To adjust for topography, topographic data must be input. If calculations are being made for one point only, AIRMOD will request the elevation at that point and the elevation at the source. If more than one point is being used, however, topographic data for each point is included with the distance data discussed above. When AIRMOD requests:

Name of distances input file:

the user then types either (1) the name of an existing file containing distance data, or (2) the name of the file about to be created. The procedure is identical to that for the "detailed" option except that elevation for each point is included in the distances file after each input distance. If the "topographic" option were selected, a sample input file might be

| | | |
|---|---|---|
| 0 | 500 | 875 |
| 0 | 1000 | 880 |
| 8 | 500 | 920 |
| 8 | 1000 | 523 |

where the last figure on each line is the elevation (in meters). As for the "long" and "detailed" option, AIRMOD will request the necessary data one piece at a time if it has not previously been prepared. Again, this data may then be referred to in future AIRMOD sessions by the user-assigned name.

## Help

The user may ask for assistance at any time in an AIRMOD session by typing "?". For example, the user may request help on the emission rate of a source by typing "?". AIRMOD will then suggest some reasonable emission rates for various types of pollutant sources. When puzzled or in need of further explanation, simply type "?".

Figure 2 is a transcript of an actual AIRMOD session. The user's input is underlined; AIRMOD's response is in regular type. The session will start from the initial log-in.

Welcome to CERL's:

Environmental Technical Information System

What program? (type <cr> to see list) 5

WELCOME TO AIRMOD

Model type: short-term point-source model
Distance from source to point (meters): 500
Emission rate (gram/sec): 100
Stack height (meter): 25
Stack diameter (meter): 2
Stack gas exit velocity (meter/sec): 5
Stack gas at temperature (degrees K): 400
Ambient temperature (deg K): 300
Max positive lapse rate (deg/m): ?

The maximum positive lapse rate is the temperature gradient in the atmosphere. This number is not critical -- it is used only for calculating buoyant plume rise in a stable atmosphere. It is never greater than 0.01 deg K. If you type in a greater number, 0.01 will be assumed.

Max positive lapse rate (deg/m): .01

Source characteristics:

| | | | |
|---|---|---|---|
| Emission rate | = | 100.00 | grams/sec |
| Stack height | = | 25.00 | meters |
| Stack diameter | = | 2.00 | meters |
| Stack gas exit velocity | = | 5.00 | meters/sec |
| Stack gas temperature | = | 400.00 | degrees K |
| Air temperature | = | 300.00 | degrees K |
| Max positive lapse rate | = | 0.0100 | degrees/meter |

DIRECTION = NORTH (0)

Concentration in micrograms/cubic cm

| Stab Class | wind 1 | wind 2 | wind 3 | wind 4 | wind 5 | wind 6 |
|---|---|---|---|---|---|---|
| 1 | 0.0002 | 0.0005 | 0.0006 | 0.0006 | 0.0006 | 0.0005 |
| 2 | 0.0000 | 0.0004 | 0.0007 | 0.0008 | 0.0008 | 0.0007 |
| 3 | 0.0000 | 0.0003 | 0.0006 | 0.0007 | 0.0007 | 0.0006 |
| 4 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Figure 2. Transcript of AIRMOD session.

## 5 CONCLUSION

Documented in this report are user requirements related to air quality impact analysis in quantitative terms as required for the preparation of Environmental Impact Assessments and Statements. An initial air quality impact model design and configuration was formulated. This formulation was based upon review of existing models and modification of existing technology to meet Army users' needs.

This initial air quality impact model design and configuration will be studied further and systematized into an operating model. Information provided in the report can be used for initial air quality impact analysis.

## APPENDIX: STABILITY CLASSES

When a gaseous pollutant is released to the air, it begins to disperse. The physical process that transports the molecules of pollutant from one point to another is eddy diffusion, or turbulence. This is a random, or nearly random, motion of a large number of molecules and is physically related to the temperature stratification of the atmosphere and to the wind field. This leads to the concept of stability classes. Stable layers are those in which large-scale turbulence is suppressed, while unstable layers allow relatively free mixing.

Pasquill[7] divided stability conditions into six classes, A through F (see Table A1). The determination of these classes is shown in Table A1. Solar radiation (Table A2) is estimated as (1) strong (if atmosphere is clear at solar altitudes greater than 60 degrees), (2) moderate (if only solar altitudes between 35 and 60 degrees have clear skies), and (3) slight (if only solar altitudes less than 35 degrees have clear skies.)

The American Society of Meteorological Engineers (ASME)[8] has divided stability conditions into four classes, each one somewhat broader than those defined by Pasquill. These classes are numbered 1 to 4. Their relationship to classes defined by Pasquill is shown in Table A2. For AIRMOD purposes, the ASME classes have been used since, in practice, the distinction between classes such as "stable" and "extremely stable" is somewhat arbitrary and makes little difference to the calculations. Three other classes have been added to allow AIRMOD to incorporate inversion conditions. These are not true classes per se but are a combination of two of the other classes.

Inversion occurs when a nonstable layer is overlain by a stable layer at some height, known as the mixing height (or lid height). Three types of inversion are used in AIRMOD: (1) very unstable overlain by stable, (2) unstable overlain by stable, and (3) neutral overlain by stable. This situation is depicted in Figure A1.

---

7 Pasquill, F., *Atmospheric Diffusion* (Van Nostrand, 1962).
8 *Recommended Guide for the Dispersion of Airborne Effluents*, second edition (ASME, 1973).

Table A1
Stability Class Correlations

| Pasquill Classes | | ASME Classes | |
|---|---|---|---|
| A | Extremely unstable | 1 | Very unstable |
| B | Unstable | | |
| C | Slightly unstable | 2 | Unstable |
| D | Neutral | 3 | Neutral |
| E | Stable | 4 | Stable |
| F | Extremely stable | | |

Table A2
Estimation of Stability Class

| Surface Wind | Day: Incoming Solar Radiation — Strong | Moderate | Light | Night: 4/8 clouds | 3/8 clouds |
|---|---|---|---|---|---|
| <2 m/sec | A | A | B | | |
| 2-3 m/sec | A-B | B | C | E | F |
| 3-5 m/sec | B | B-C | C | D | E |
| 5-6 m/sec | C | C-D | D | D | D |
| 6 m/sec | C | D | D | D | D |

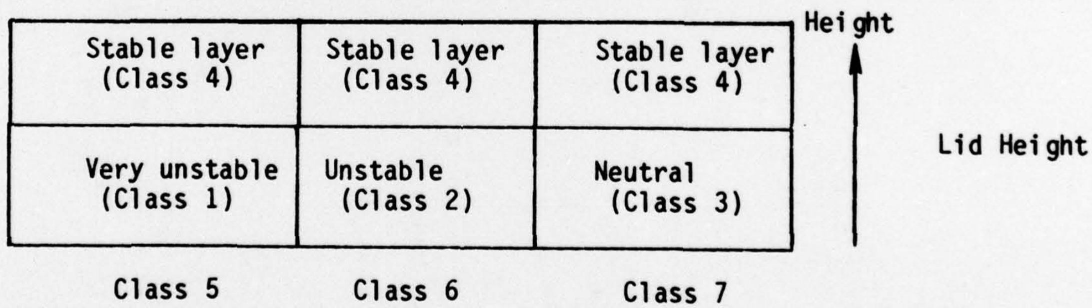


Figure A1. Stability classes for inversion classes.

Thus, AIRMOD uses seven stability classes -- the four defined by ASME plus three pseudo-classes describing inversion conditions. The stability class is tied closely to the wind speed. A given stability class may only exist within a certain range of wind conditions. So for each of the seven stability classes; six wind classes are defined for each of the seven stability classes as shown in Table A3.

Table A3
Wind Speeds for Stability Classes

| | Wind m/sec Class (in m/sec) | | | | | |
|---|---|---|---|---|---|---|
| Stability Class | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 Very unstable | 0.9 | 1.3 | 1.8 | 2.2 | 2.7 | 3.1 |
| 2 Unstable | 0.9 | 1.8 | 2.7 | 3.6 | 4.5 | 5.4 |
| 3 Neutral | 2.7 | 4.5 | 6.3 | 9.8 | 13.4 | 17.0 |
| 4 Stable | 1.8 | 2.7 | 3.6 | 4.5 | 5.4 | 6.3 |
| 5 Inversion-1 | 0.9 | 1.3 | 1.8 | 2.2 | 2.7 | 3.1 |
| 6 Inversion-2 | 0.9 | 1.8 | 1.7 | 3.6 | 4.5 | 5.4 |
| 7 Inversion-3 | 2.7 | 4.5 | 6.3 | 9.8 | 13.4 | 17.0 |

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